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The Experimental Study of the Effect of Flow Pattern Geometry on Performance of Micro Proton Exchange Membrane Fuel Cell

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***Abstract*—**In this research, the flow pattern influence on performance of a micro PEMFC was investigated experimentally. The investigation focused on the impacts of bend angels and rib/channel dimensions of serpentine flow channel pattern on the performance and investigated how they improve the performance. The fuel cell employed for these experiments was a micro single PEMFC with a membrane of 1.44 cm^2 Nafion NRE-212. The results show that 60° and 120° bend angles can provide the better performances at 20 and 40 sccm inlet flow rates comparing to that the conventional design. Additionally, wider channel with narrower rib spacing gives better performance. These results may be applied to develop universal heuristics for the design of flow pattern of micro PEMFC.

***Keywords*—**Flow pattern, MEMS, PEMFC, Performance

I. Introduction

FOR the need of portable power devices, micro Proton exchange membrane fuel cell (PEMFC) with high efficiency and zero emission has attracted the attention from researchers. Using micro-electro-mechanism systems (MEMS) can significantly miniaturize the size of PEMFC, however, micro-scale effect should be studied to understand the flow mechanism within PEMFC. An ideal flow pattern is necessary for the high uniformity of reactants so that improvement of performance and water management can be achieved. With poor water management, flooding effect would exist in a fuel cell, and seriously decreases the performance, especially in a micro PEMFC. Therefore, developing flow pattern is required for the appropriate design of micro PEMFC.

Early in 2000, S. J. Lee *et al.* [1] used micro fabrication techniques, such as deep silicon etching, photo masked electroplating, physical vapor deposition, anodic bonding, and spin coating on the silicon wafer to create flow channels. They produced a milliwatt micro fuel cell using novel techniques and materials. The micro fuel cell has a maximum output of 150 mA/cm^2 current density. S. S. Hsieh *et al.* [2] developed a new design and fabrication process for a micro fuel cell flow field plate with a cross section of 5 cm^2 and a thickness of 800 μm. The novel design had a reported 25 mW/cm^2 power density at 0.65 V at ambient temperature. S. S. Hsieh [3] used the SU-8 photoresist microfabrication process to fabricate micro PEMFC flow channels. The polarization curve shows a modest voltage drop over a very small range of currents. Their work contributed to the low-cost mass-produced of small flat single fuel cell with 30 mW/cm^2 power density at 0.35 V. In 2006, S. W. Cha *et al.* [4] studied transport phenomena in micro fuel cell flow channels. The channels were 500 μm, 100 μm and 20 μm wide and manufactured using a structural photopolymer. The effects of the channel size and the gas diffusion layer thickness were examined. A high pressure drop in very small channels improved the convection of air into the gas diffusion layer (GDL) and improved fuel cell performance at low current density. The results revealed that using thin GDL improve the performance of micro fuel cell.

To study the influence of flow pattern design, many investigations had been made. S. Shimpalee et al. [5] investigated various channel path lengths to estimate the impact of flow path length on temperature distributions, current density distributions and the performance. According to their numerical results, local temperature, water content and current density distributions become more uniform under serpentine flow-field designs with shorter path lengths or greater number of channels. Karvonen et al. [6] proposed a parallel flow pattern tht has uniform flow distribution by both numerical and experimental analysis. The inlet distributor of flow pattern is narrowed which leads to better equality of flow velocities in different channels. And the difference between the largest velocity and the smallest is decreased from 16% to 8% with narrowed inlet channel. S. Shimpalee and J. W. Van Zee [7] numerically investigated how serpentine flow fields with different channel/rib cross-sectional areas affect performance and species distributions for both automotive and stationary conditions. Their simulation results revealed that for a stationary condition, a narrow channel with wide rib spacing improves performance; however, the opposite occurs when the automotive condition is applied. Another numerical investigation on the influence of flow pattern geometry was carried out by Jeon et al. [8] for four 10 cm^2 serpentine

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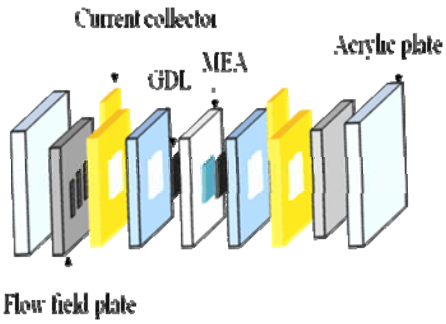
flow-fields with single channel, double channel, cyclic-single channel and symmetric-single channel patterns at 100% and 64% inlet HR. According to their results, the double channel flow-field was found to have the highest performance at 100% inlet HR and to have most uniform current density distribution. However, for 64% inlet HR, there were little difference on performance and current density uniformity among the four serpentine flow-field patterns. R. Boddu [9] proposed a three-dimensional CFD model with different bend configuration and number of channels to study the effect of flow channel on velocity distribution and pressure drop. The results show that the serpentine square bend exhibits consistently higher pressure drops compared to curvilinear bend. Additionally, with the increased number of channels, a more effective contact surface can be achieved.

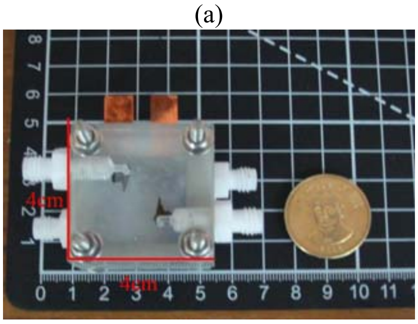
This paper using MEMS technology has experimentally studied the performance of a 1.44-cm^2 micro PEMFC with different flow patterns under different inlet flow rates. And the experimental results would be compared and discussed.

II EXPERIMENTAL SET UP AND PROCEDURE

Micro PEMFC has several components, which are the end plate, the gasket, the GDL, the membrane electrode assembly (MEA), the flow pattern and the current collector. Figure 1a schematically shows the micro PEMFC. And figure 1b displays the single micro PEMFC fabricate with all of the components.



(a)



(b)

Fig. 1 (a) Scheme of micro PEMFC; (b) Picture of micro PEMFC.

In this study, three patterns with different bend angles are manufactured to study the influence of bend angles on PEMFC performance. Figure 2 shows the three different patterns which are under investigation. They are (a) 30-150, (b) 60-120 and (c) 90-90, respectively. The first number showing in each pattern represents the first angle of the channels, and the latter one represents the second angle. These two angles combine to make a complete u-turn flow channel. Also, to study the influence of rib/channel dimension on the performance, three patterns with different rib/channel dimension are shown in Fig. 3.

(a) (b) (c)

Fig. 2 Flow Patterns in micro PEMFC (a) 30-150, (b)60-120 and (c) 90-90.

(a) (b) (c)

Fig. 3 Flow patterns in micro PEMFC (a) rib/channel 500/700 µm, (b) rib/channel 800/400µm and (c) rib/channel 100/500 µm.

A micro PEMFC is setup to obtain the polarization curves. The end plate is made of acrylic and its size is 45×45×13 mm. The gasket is to isolates and prevents gas leakage; it is made of silica gel with thickness of 1 mm. The GDL used herein is standard carbon paper (CARBEL CL GDL) with a thickness of 0.4 mm. The Nafion NRE-212 MEA (thickness: 0.035 mm, catalyst loading of anode and cathode: 0.5 mg/cm^2 Pt) is loading 0.5 mg/cm^2 Pt/C on both anode and cathode sides.. The micro PEMFC reaction area is 1.44 cm^2.

Silicon is used as the material of the substrate in the anode and cathode flow patterns. The flow patterns are formed using a MEMS technology. Figure 4 depicts the procedure for fabricating the silicon wafer. A 6-inch diameter silicon wafer is used as the substrate in this manufacturing.

Contaminants on the surface of silicon wafers at the start of the MEMS technology process or accumulate during processing must be removed to obtain high performance and highly reliable semiconductor devices, and prevent equipment contamination, especially under high temperature oxidation, diffusion and deposition tubes. Therefore, the Radio Corporation of America (RCA) cleaning a standard set of wafer cleaning steps needs to be performed before high temperature processing steps (oxidation, diffusion, chemical vapor deposition (CVD)) of silicon wafers in semiconductor manufacturing.

A spinner is used to dry the wafer after RCA cleaning. Next, a 200 nm Aluminum is deposited by Sputter; one side of the silicon wafer is polished, and silicon substrate is then spin-coated a Photoresist AZ4620 with thickness of 7 µm.

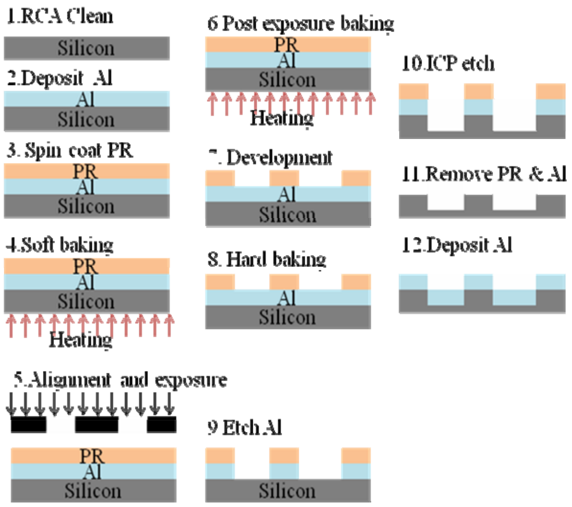


Fig. 4 Silicon wafer etching process.

The silicon substrate is soft-baked subsequently. Soft baking is the step during which almost all of the solvents are removed from the photoresist coating. Ultraviolet light with a g-line is used for the exposure process. After exposure has been completed, heat is applied again at 120°C for 90sec preparing for post exposure baking. The flow channels are developed in AD-10 for around a hundred seconds.

After that, the photoresist is hard-baked at 110°C for 60sec. The silicon substrate after development is patterned by wet etching.

The exposed silicon wafer is etched away to pattern micro PEMFC channels in an Aluminum solvent at 80°C. Next, the resist is removed from the silicon substrate. Afterward ICP (Inductively Coupled Plasma) is conducted to etch silicon of depth 464 μm using chemically reactive plasma to remove silicon structure. Finally, the silicon wafer with 200 nm aluminum thick was deposited by Sputter.

The holes for feeding fuel are opened by drilling from the rear. The diameter of silicon wafer is 6 in containing 16 flow patterns, each with 1.44 cm^2 effective reaction area.

The anode and cathode flow pattern of the micro PEMFC were supplied with pure hydrogen and oxygen without humidification. Both input gases were maintained at 23°C, and supplied to the single cell at near-ambient pressure.

Input gas flow rates and temperature were controlled with an automatic fuel cell test station developed by industrial technology research institute (ITRI) in Taiwan, ROC. An overview of the reference operating parameters utilized with the measurements is presented in Table 1.

The measurements were started after an MEA activation procedure that provides a stable open circuit voltage (OCV) and current output for each voltage. The polarization and power curves consist of points measured each 0.05 V from OCV to 0.2 V at 30 second operation. If stable operating conditions could not be achieved, the measurements were neither considered in the subsequent analysis nor the plots presented within this paper.

TABLE I OPERATING PARAMETERS

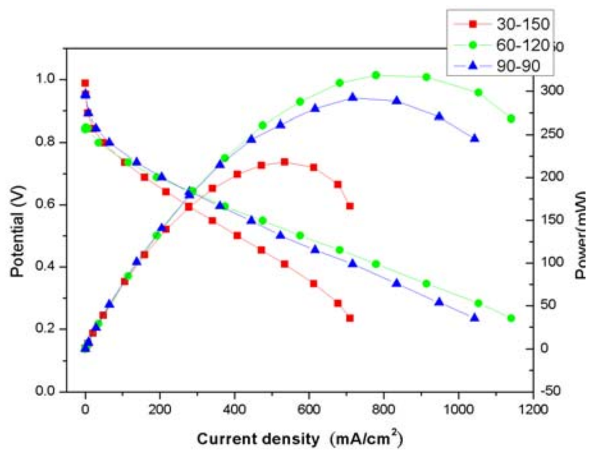
Inlet temperature	23°C
Fuel pressure	1 atm
Oxygen pressure	1 atm
Anode gas	hydrogen
Cathode gas	oxygen

III. RESULTS AND DISCUSSIONS

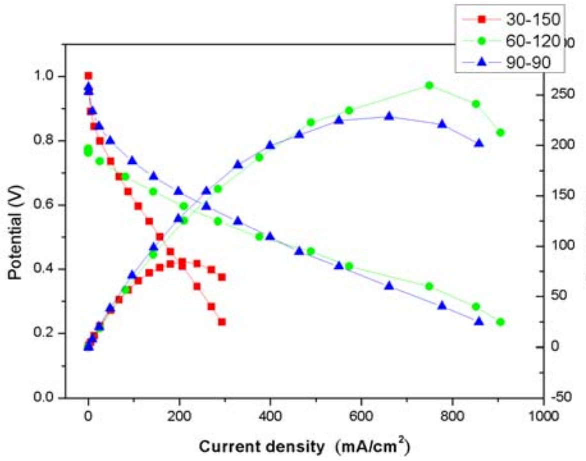
The experimental test of 1.44 cm^2 serpentine with different bend angles and rib/channel dimensions under three different inlet flow rates are studied to investigate the effect of flow pattern geometry on the performance of micro PEMFC. The reference case is selects as 90–90 flow pattern since it is the most common channel configuration studied in the majority of researches. Also, the advantages of the configurations are discussed and analyzed.

3.1 The effect of bend angles

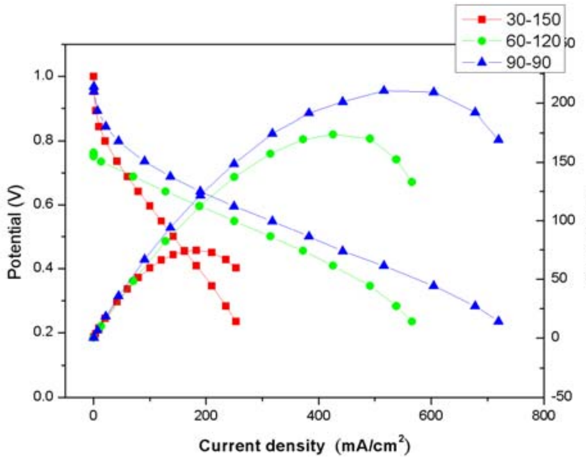
Figure 6 shows the resultant polarization and power curves of the three patterns with different bend angles at 20, 40 and 60 sccm inlet flow rate with gases supplied in counter-current direction. The comparison indicates that the 60-120 pattern is slightly having better performance ranged from 0.7V to 0.2V at 20 sccm and 0.4V to 0.2V at 40 sccm, indicating that the higher uniform reactant distributions are achieved within the 60-120 micro PEMFC. The performance of 60-120 pattern is about 8% larger than 90-90 and 31.38% larger than 30-150 pattern at 0.4V. However, at high flow rate (60 sccm) 90-90 is having better performance, 21.37% larger, compared to 60-120. Also, the figure indicates that the performance decreases with the increase of inlet flow rate since the high flow rate increases convection rate, and therefore, reduce the diffusion rate and lower the ability the reactants' penetration through porous media for the reaction. Since the operating temperature is low, the dehydration of membrane doesn't cause a significant voltage drop at high current densities for 60-120 and 90-90 patterns. However, there exists a significant voltage drop in 30-150 pattern due to the poor water management and large hydraulic resistance caused by large bend angles.



(a) 20 sccm



(b) 40 sccm

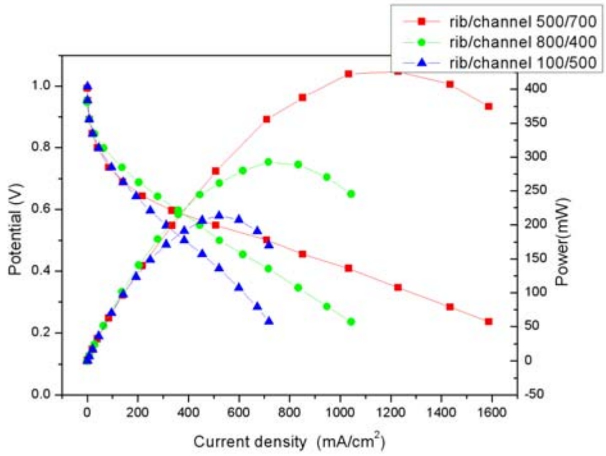


(c) 60 sccm

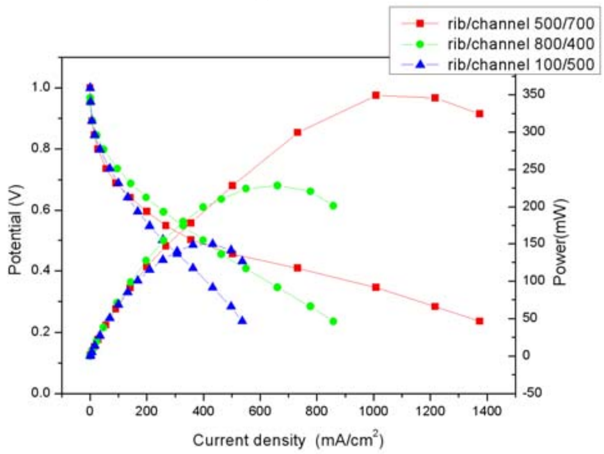
Fig. 5 Polarization curves of three bend angles under different inlet flow rates.

3.2 The effect of rib/channel configuration

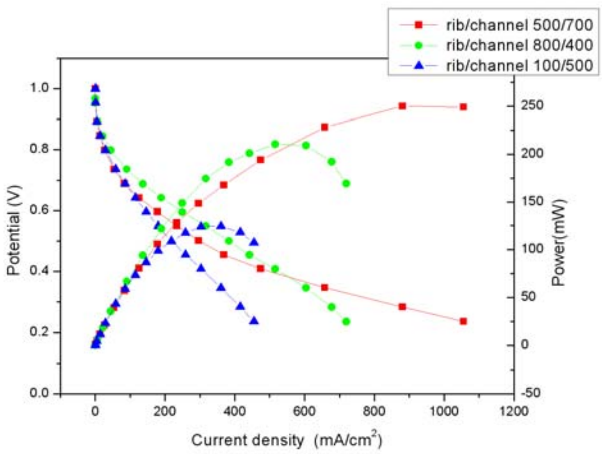
Another test for the effect of rib/channel dimension on micro PEMFC performance was also studied. The test was performed under three different rib/channel dimensions of 90-90 pattern, the most conventional pattern, 800/400 µm, 500/700 µm and 100/500 µm with three different inlet flow rates, 20, 40 and 60 sccm, respectively. Figure 7 shows the resultant polarization and power curves of the patterns with reacting gases supplied in counter-current direction. The results reveal that the pattern with wider channel (rib/channel 500/700 µm) has better performance compared to narrower ones after operating voltage drops below 0.6V at 20 sccm, 0.4V at 40 sccm and 0.35V at 60 sccm. Further, the pattern with wider channel (rib/channel 500/700 µm) gives around 25% and 50% higher current densities compared to the patterns with narrower channel (rib/channel 800/400 µm and rib/channel 100/500 µm) at 0.4V with inlet flow rate of 20 sccm. In this case, with wider configuration, the length of channel can be reduced so that flow resistance decreases, also the effective reaction surface increases and alleviates the concentration losses, therefore, the performance is incrementally improved. This figure also indicates that rib/channel dimension has more impact on the micro PEMFC performance than inlet flow rate does. Again, the performance also decreases with the increase of inlet flow rate. This phenomenon applies to all configurations in this study.



(a) 20 sccm



(b) 40 sccm



(c) 60 sccm

Fig. 6 Polarization curves of three rib/channel dimensions under different inlet flow rates.

IV. CONCLUSIONS

In this paper, the effects of several flow pattern designs on micro PEMFC were experimentally studied. The polarization and power curves with their different inlet flow rates, 20, 40, and 60 sccm, were analyzed and compared, and the results of this analysis are summarized as follows:

1. 60-120 pattern has improved the performance of micro PEMFC under inlet flow rate of 20 and 40 sccm compared to 90-90, the conventional design.
2. The performance of micro PEMFC decreases with the increase of inlet flow rate.
3. The performance is higher for the wider channel with narrower rib configuration.
4. The rib/channel width effect shows more sensitive to the micro PEMFC performance than inlet flow rates.

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